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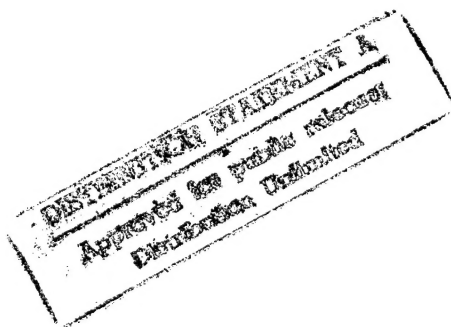
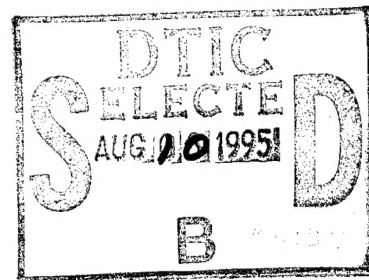
Aircraft Evacuations Through Type-III Exits I: Effects of Seat Placement at the Exit

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| 16. Abstract <p>INTRODUCTION. Simulated emergency egress from Type III over-wing exits was studied to support regulatory action by the FAA. Passageway width and seat encroachment distance adjacent to the Type-III exit were the major variables of interest. METHODS. Two subject groups of differing mean ages were employed in a repeated-measures evaluation of different passageway widths leading to the exit in the CAMI aircraft cabin evacuation facility. Main effects of passageway width and seat encroachment distance on egress rates were determined using analysis of variance (ANOVA); RESULTS. Main effects were found for passageway width ($p < .001$), seat encroachment distance ($p < .001$), and subject group ($p < .001$). The passageway width resulted from slowed egress at 6 and 10 inch wide passageways relative to 13, 15, and 20 inch passageways; seat encroachment effects were found for maximum seat encroachments but not midpoint and minimum encroachment distances. The subject group effects were found to result from a general increase in egress time for the older subject group. CONCLUSIONS. The placement of seat assemblies at the Type-III exit has significant effects on passenger egress through the exit opening. Narrow passageways and/or large encroachments of the seat into the area of the exit opening delay egress significantly. Relative to the younger subjects, older subjects were found to have a general increase in egress times at all seat placement configurations that did not appear to worsen as the access route to the exit was made more restrictive.</p> | | | |
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Aircraft Evacuations Through Type-III Exits

I: Effects of Seat Placement at the Exit

INTRODUCTION

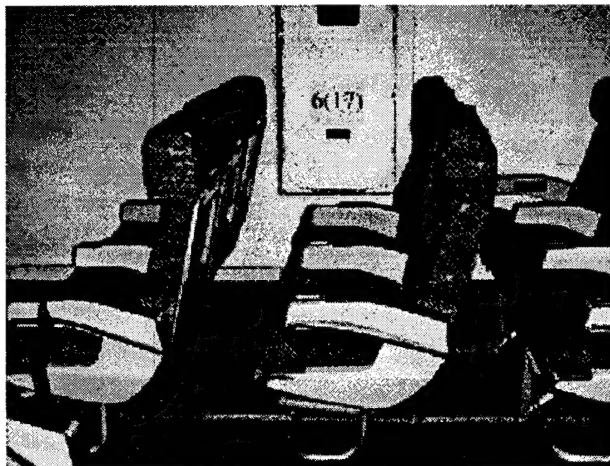
Passenger access to aircraft exits is a critical variable in emergency evacuations. In recognition of this principle, the Federal Aviation Administration (FAA) has established several Federal Aviation Regulations (FARs) to assure that transport category aircraft are designed and manufactured to provide adequate access to exits. Included are regulations on emergency exits (FAR 25.807) and their arrangements (FAR 25.809), emergency egress assist means and escape routes (FAR 25.810), aisle width (FAR 25.815), and emergency exit access (FAR 25.813). Access requirements mandated in FAR 25.813 include uniform distribution of exits, cross aisles between main cabin aisles at the exits, and passageways leading from the main aisles to the exits. Each of these rules is specified in terms of the minimum criteria necessary for compliance; combined, these FARs assure that transport category aircraft provide sufficient evacuation capability to comply with FAR 25.803, Emergency Evacuation.

The specific criteria in these FARs have been derived from historical accounts of actual evacuations, evacuation demonstrations, and dedicated research.

The criteria have evolved with the advent of new aircraft designs, as actual evacuations and evacuation demonstrations have sometimes identified potential deficiencies in then-current design parameters and/or operating procedures which might impact emergency evacuation capability. At such times, this knowledge has then been applied in dedicated research studies to identify more appropriate solutions (Collins & Wayda, 1994; see evacuation, pg 55), and therefrom, new regulatory criteria.

An example of this process is related to the passageway width leading from the aircraft center aisle to the Type-III overwing emergency exit hatch. Until 1992 a minimum passageway width had not been specified in the FARs, but it had been typically established at 6 inches, i.e., only slightly wider than the seat pitch that existed throughout the aircraft (see Figure 1). Historically, there had been a few evacuations which suggested that a wider passageway could be beneficial, and a public technical conference was held in September 1985 to address issues related to emergency aircraft evacuation. As a result of questions posed about access to exits at the

FIGURE 1



Six-inch passageway with maximum encroachment

FIGURE 2



Twenty-inch passageway with minimum encroachment

conference, two studies were conducted to address this issue (e.g., Muir, Marrison & Evans, 1989; Rasmussen & Chittum, 1989). The results of these studies indicated a potential benefit in widening the passageway. In response, and citing a similar increase in British access standards required by British Civil Aviation Authority Airworthiness Notice (AN) 79, the FAA issued a Notice of Proposed Rulemaking (NPRM) in April 1991, intending to increase the access passageway leading between triple seat assemblies to Type-III exits to a width of 20 inches with a forward offset of the passageway no greater than 5 inches. Offset was defined as the horizontal displacement of the centerline of the exit passageway.

Industry comments in response to the April, 1991 NPRM questioned whether such a dramatic increase in passageway width was necessary, and these comments spawned additional studies of access to exits, including two which addressed several different passageway widths leading to both single and dual configurations of Type-III exits (see Muir, Bottomley & Hall, 1992; McLean, Chittum, Funkhouser, Fairlie & Folk, 1992). In addition to addressing industry concerns, the findings of these studies supported the recommendations in the NPRM that FAR 25.813 be amended to require a 20-inch passageway between triple seats leading from the nearest aisle to the Type-III overwing exit.

On May 4, 1992, the FAA published in *The Federal Register* a final rule (57 FR 19220) on aircraft seating configurations at Type-III exits, entitled, "Improved Access to Type-III Exits." This rule amended FAR 25.813 (and thus FAR 121.310) for transport category aircraft, requiring that the passageways leading from the nearest aisle to a single Type-III overwing exit be maintained at a minimum width of 20 inches, with the seat assembly aft of the exit opening positioned with the front edge of its seat cushion located no more than 5 inches forward of the aft boundary of the Type-III exit opening (see Figure 2). To accomplish this task, manufacturers and air carriers would generally be required to widen the existing passageways on their aircraft by mov-

ing the seat assemblies both forward and aft of the exit opening to provide the necessary passageway width and seat assembly offset.

As a result of this change in configural and operating requirements, the Air Transport Association and individual air carriers petitioned the FAA for approval of deviations from the new rule. The petitions were based on the revenue impact of the required changes, and (citing Muir, *et al*, 1992) suggested that some as-yet-unknown narrower passageway width could provide an equivalent level of safety to the new 20-inch minimum. However, no systematic analysis of the net safety impact was generally provided. To provide the necessary data to support decisions about appropriate deviation limits, the Transport Airplane Directorate of the FAA requested another study of simulated emergency evacuations accomplished through Type-III overwing exits approached via different passageway widths and offsets (developed in this study as the distance of forward encroachment the aft seat into the exit opening) achieved by various seat assembly placements. The resultant study is described herein.

METHODS

SUBJECTS: Two groups of 37 subjects were employed in the study. The groups were roughly matched on weight and height, with nearly equal gender representation; subject age was the primary grouping factor. Group 1 subjects ranged in age from 18 to 40 years (mean = 27 yrs), whereas Group 2 participants were between 40 and 62 years old (mean = 47 yrs). Subject experience with transport category airplanes and information about emergency evacuation procedures were controlled by allowing subjects to learn how to climb through the Type-III exit at the beginning of each group's participation.

DESIGN: Both groups of subjects completed a series of simulated emergency evacuations using a Type-III exit approached via 5 different passageway widths (6, 10, 13, 15 & 20 inches) and 3 seat encroachment distances (a 5-inch minimum, a 10-inch midpoint, and a 15-inch maximum) in a counter-

balanced research design. Each trial series required 3 consecutive mornings for each group to complete the total of 30 trials. The trial series began with the learning exercise, which was accomplished with the seat assemblies adjacent to the Type-III exit removed. Using this configuration, subjects were allowed to climb through the exit opening, learning how to exit as quickly as possible. After only 2 such trials for each group, the subjects were performing asymptotically, as determined in a pilot study. The subjects then began the experimental series.

MOTIVATION: To encourage an optimum level of subject performance throughout the study, a "competitive cooperation" was established among subjects to serve as a motivational mechanism. Subjects were instructed that a (unspecified) bonus would be paid to the top 3 performers in the group, i.e., those who had the fastest mean individual evacuation times across all trials. Subjects were required to sit at a different location on every trial to counterbalance seat/exit proximity effects on the mean times, and they were also instructed that they could not jump ahead in the egress queue, shove other subjects out of the way, or impede other subjects in any way. The key to success, they were told, was to be as individually fast as possible by helping their fellow subjects to be as fast as they could. In addition to this motivational technique, two airline flight attendants participated in the evacuation trials to further maintain high levels of motivation and promote effective egress. Of these, one flight attendant was stationed at the rear of the cabin to urge subjects forward, while the other one was placed in the outboard seat in the row just ahead of the Type-III exit. At the start of a trial, the forward flight attendant would turn around, stand up, and offer encouragement to subjects during the evacuation.

PROCEDURE: Subjects began each trial sitting in six-abreast seat assemblies located both forward (40%) and aft (60%) of the single starboard Type-III exit. This exit was the only egress route available. A buzzer was used to signal the start of the trial, whereupon the Type-III exit cover was immediately removed from outside the aircraft simulator

by a research confederate. Each evacuation was timed and archived using videotape imprinted with time codes. At the conclusion of each trial, subjects were assembled outside the aircraft simulator for about 10 minutes to await the reconfiguration of the seat assemblies to form a different passageway width and encroachment distance, after which they re-entered the simulator for another trial.

Group total evacuation times for each trial were manually extracted from the videotapes, and these data were analyzed using *SPSS for Windows*^o, Release 6.0.

RESULTS

Group evacuation times include the first 35 subjects in each group, as the last 2 subjects in each group were omitted to control for possible changes in performance related to their rearward positions in the queue. The results obtained for both groups were remarkably consistent across trials, showing effects of passageway width, seat encroachment, and subject group. Group evacuation times from the last trial conducted at the end of each experimental session differed by less than a second from the initial experimental trial for both groups, using the same 20-inch passageway width and 5-inch encroachment distance seat placement as a control condition. This consistency appears to have resulted from both the motivational controls employed and the training/learning regimen that the subjects were allowed to complete before the actual experimental trials were started. These data may thus be viewed as a "benchmark" of seat placement effects, essentially free of unwanted variance produced by human performance confounds related to changes in experience, fatigue, and/or motivation level.

A 3-way (subject group x passageway width x encroachment distance) analysis of variance (ANOVA) revealed significant main effects for group ($p < .001$), passageway width ($p < .001$) and encroachment distance ($p < .001$), without significant interactions between any variables. Differences in evacuation times, based on passageway width, are

FIGURE 3

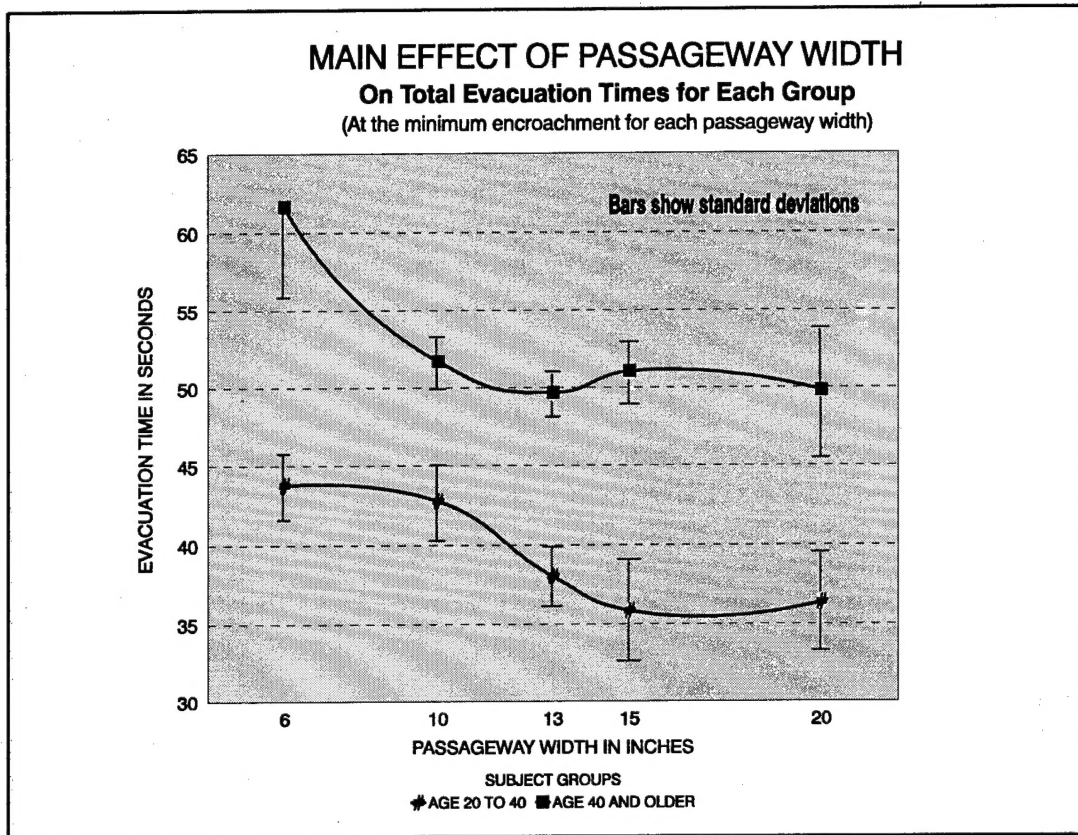
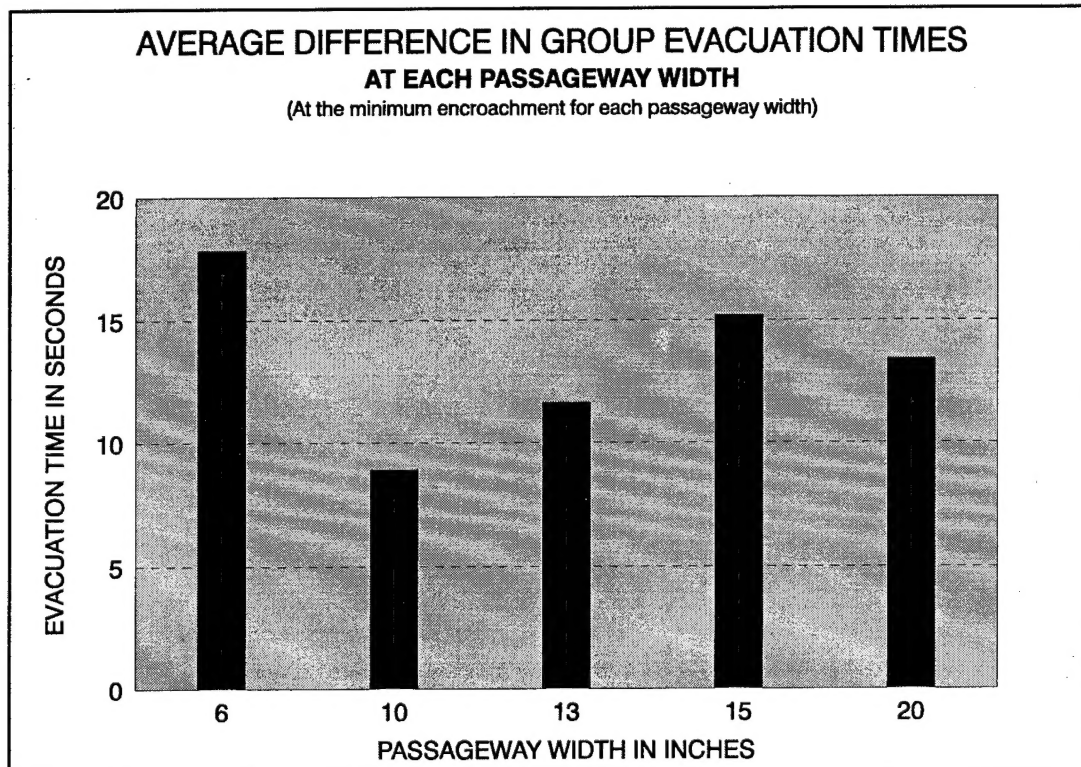


FIGURE 4



shown by subject group in Figure 3. Simple main effects ANOVAs on group evacuation times revealed effects of passageway width for both the younger ($p < .001$) and the older ($p < .025$) groups. Duncan's Multiple Range Tests indicated that both the 6-inch and 10-inch passageways produced significantly slower evacuation times in the younger group, but only the 6-inch passageway width was shown to produce significantly slower evacuation times for the older group ($p < .05$).

These group effects appeared to result from the reduced athleticism and agility of the older subjects in Group 2, as indicated by difficulties in approaching and stepping through the exit opening, especially with the narrower passageway widths and/or greater encroachment distances. In fact, these difficulties during Group 2 trials prompted the forward flight attendant to (carelessly and unexpectedly) instruct the subjects to crawl over the seats to egress. This unintended change in experimental instruction set appeared to produce a relative enhancement of Group 2 performance at the narrower passageway widths, and led the research team to truncate the number of

Group 2 evacuation trials, since the study had begun to measure "seat-stepping" time instead of seat placement effects. Note in Figure 4 the improvement in Group 2 egress time at the 10-inch passageway width, relative to Group 1. This relative improvement did not affect the 6-inch passageway width data, which were gathered before the change in instructions had occurred.

A simple main effect of encroachment distance was significant for the younger group ($p < .03$), but the encroachment distance effect failed to achieve statistical significance for the older group ($p < .30$). Duncan's Multiple Range Tests showed that, for the younger group, the maximum encroachment distance was significantly different ($p < .05$) from the midpoint and minimum encroachment distances, which were statistically similar. Given the apparent similarity of encroachment distance effects for both groups, it is likely that the failure to find significance for the older group was related to the larger variance in the Group 2 data (see Figure 5), as well as the reduced number of Group 2 trials, which reduced the statistical power of the design.

FIGURE 5

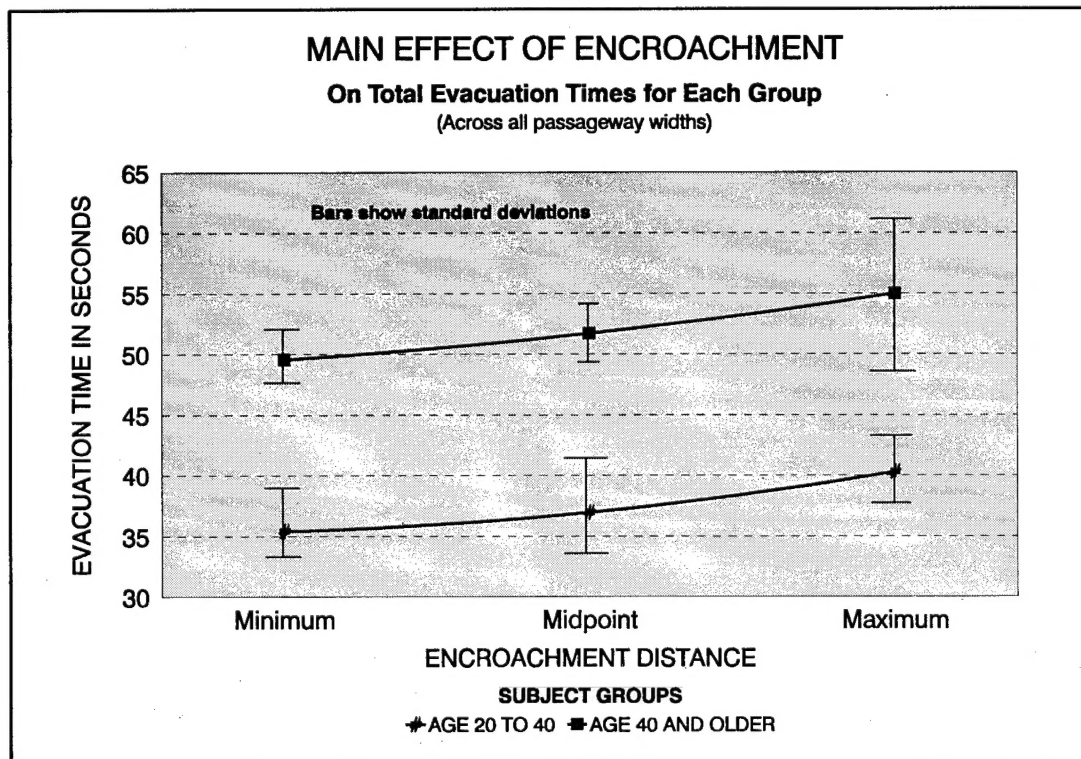


FIGURE 6

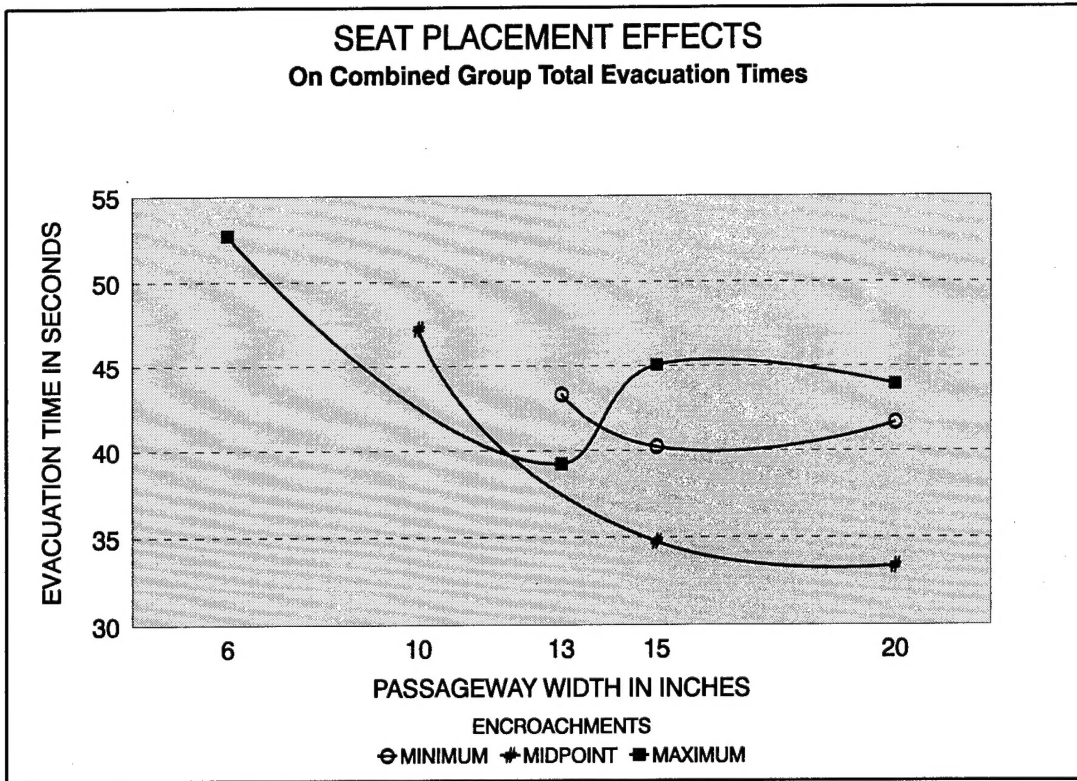
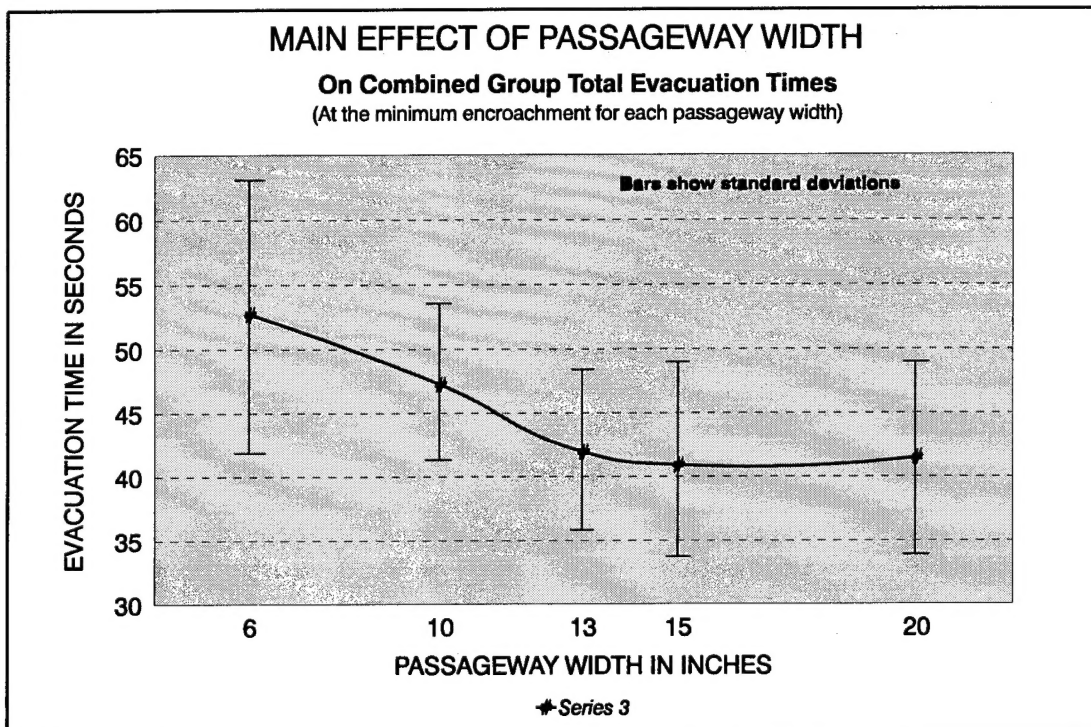


FIGURE 7



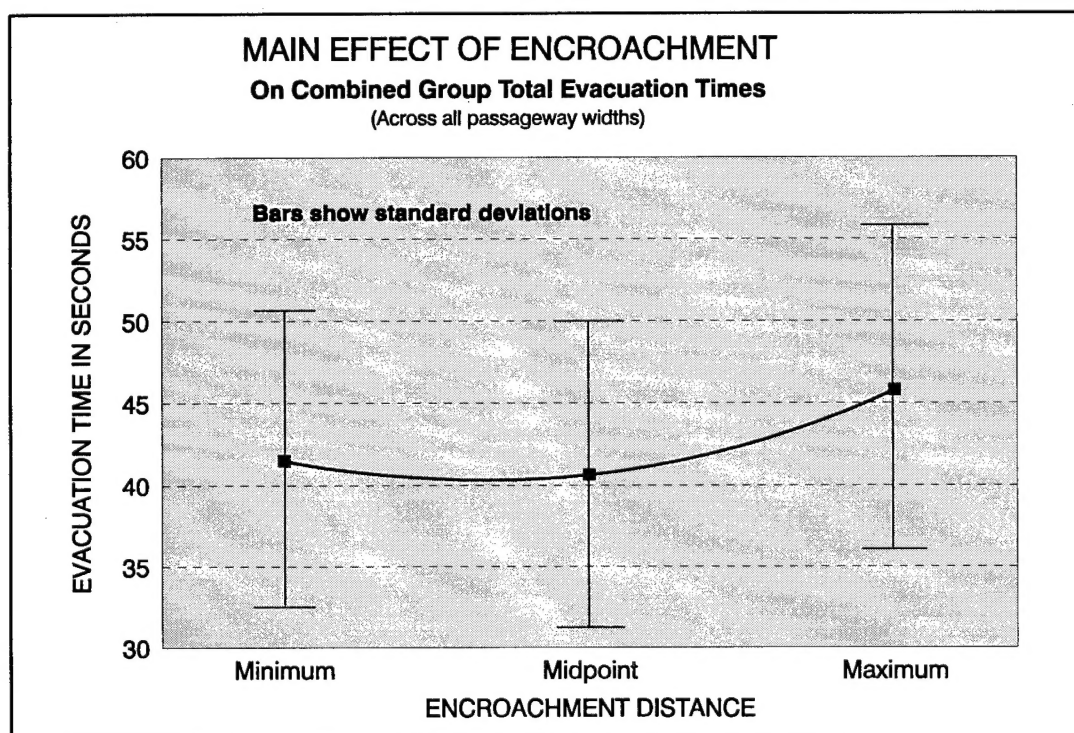
The general similarity of effects for both subject groups suggested that combining the raw data from the groups in a common data set could provide a more generalizable answer to the research question without violating the assumptions of the model. This approach was also supported by 2-way repeated-measures ANOVAs which found insignificant interaction effects for both group by passageway width ($p < .14$) and group by encroachment distance ($p < .96$). Accordingly, comparable data from both subject groups were merged in a combined data set. Figure 6 provides a composite view of the data set obtained.

Using the combined data set, a 2-way ANOVA (passageway width x encroachment distance) revealed a main effect of passageway width ($p < .05$). Duncan's Multiple Range Test indicated that only the 6-inch passageway had significantly increased egress times. Figure 7 displays passageway width effects. The effect of encroachment distance failed to achieve statistical

significance (see Figure 8), and there was no indication of any passageway width by encroachment distance interaction effect.

These combined-group results do little to enhance the generalizability of the findings, as the combined data appear to suffer from three problems. (Recall that Group 2 had fewer trials to begin with, and except for the data from the 10-inch passageway width which were the only available data at that width, the combined data set also did not include data from trials in which the older subjects had been incorrectly instructed). First, the combined data set was smaller than the entire set of Group 1 data alone; and second, the increased variability associated with combining the group data further reduced the statistical power of the design. Third, the effects of the inadvertent change in instruction set for the older group produced a change in performance that appears to have eliminated the effect of the 10-inch passageway width found for the younger group.

FIGURE 8



DISCUSSION

The ability of subjects to evacuate from an aircraft through Type-III overwing exits has been shown to depend upon several factors. Among these, subject age and seat assembly placement adjacent to the exit have been found to have systematic effects. Advanced subject age produced decrements in the speed of evacuation, relative to younger subjects, at all passageway widths and seat encroachment distances. Reducing the passageway width also led to increased evacuation times, as did increasing seat encroachment distance to the maximum allowable (using seat geometry as the limiting factor).

Both subject groups showed significant increases in evacuation time when the passageway width was reduced to 6 inches, and the younger group also had significant difficulty with the 10-inch passageway, even though the older subject group did not show this effect. However, given the relatively larger increase in evacuation time of the older group at the 6-inch passageway width (see Figure 4), this lack of a 10-inch effect was presumably caused by the careless change in instructions given the older group, i.e., "step on the seat" to get out. It probably does not reflect some "notch" function, whereby older persons have an improbable advantage at the 10-inch passageway width, relative to younger folk. The homogeneous effects of seat encroachment at all distances for both subject groups supports this interpretation.

Decreasing passageway width and increasing seat encroachment distance both functioned to reduce the available workspace at the exit proper, and this effect challenged subjects' agility and produced an increase in the effort they had to expend to egress. Returning to Figures 3 and 5, it may be seen that such workspace effects impaired the performance of both subject groups; however, the effects of seat assembly placement and age were merely additive, without systematic interactions. This, too, highlights the generalized impairment that reducing workspace via different seat placements at the exit produced, without suggesting that persons of advanced age are differentially more susceptible to minimal passageway widths and/or maximal seat encroachments.

However, a mitigating factor for this interpretation might be the training/ learning regimen allowed at the beginning of the experimental series. The opportunity for the subjects to become familiar with the Type-III exit and the approach to it could have affected the results in at least two ways: 1) learning the behavioral requirements of using the Type-III exit enhanced the physical efficiency (skill) of the older subjects, even though they were generally slower, and/or 2) enhanced knowledge about the behavioral requirements for egress through the more restrictive Type-III exit configurations allowed them to develop strategies that masked a hyperadditive interaction (synergistic) effect of increasing age and progressively more restrictive workspace. Given the data from the 6-inch passageway width, coupled with the general difficulties in egress the older subjects experienced, it is unlikely that the first explanation could prevail. The second explanation is also unlikely, as both subject groups had an equivalent learning opportunity. However, such a differential training effect should be considered a possibility, given the application of these results to questions about equivalent safety levels.

Thus, application of the results demands a studied perspective, requiring a synthesis of the findings without appeal to the absolute minimum passageway width found to produce significantly slower evacuations. The counterintuitive differences in group performance at the 10-inch passageway width could be represented as evidence for allowing a lesser passageway width than is actually required for passengers to egress promptly through a Type-III exit. Such a representation would ignore both the change in instruction set that likely enhanced the older group performance at the 10-inch passageway width, as well as the possibility that the older subjects gained knowledge and/or skill that allowed them to compensate for their age-related decrements in mobility that would not be available to less-informed older passengers. This approach would, therefore, cloud the answer to the question of what lesser passageway width provides equivalent safety to that provided by a 20-inch passageway with the minimum 5-inch offset. A more reasoned, as well as appropriately conservative, approach in designing the passageway to the

Type-III exit, would be to expect older passengers to be at least as affected by seat placement as was the more agile and faster younger subject group employed here, and use only the results from the younger subject group as guidance for choosing the minimum passageway width. Selection of an appropriate seat encroachment distance is less contentious, as both subject groups performed more poorly at the maximum, but not the midpoint and minimum distances, even though the performance of the older subject group was again relatively less affected.

Together, these results suggest that the 13-inch passageway with a midpoint encroachment distance would be the most restrictive configuration allowable to obtain evacuation performance essentially equivalent to that obtained with the 20-inch passageway offset 5 inches.

REFERENCES

- Chandler, RF; George, MH; and Pollard, DW; *Usability of Transport Aircraft Emergency Exits*, Protection and Survival Laboratory Memorandum Report AAM-119-87-3, May 27, 1987.
- Code of Federal Regulations, Title 14, Aeronautics and Space, Vol. 1, January 1, 1994.
- Collins, WE; Wayda, ME; *Index of FAA Office of Aviation Medicine Reports: 1961 - 1993*, Office of Aviation Medicine Report, DOT/FAA/AM-94/1, January 1994.
- McLean, GA; Chittum, CB; Funkhouser, GE; Fairlie, GW; Folk, EW; *Effects of Seating Configuration and Number of Type III Exits on Emergency Aircraft Evacuation*, Office of Aviation Medicine Report, DOT/FAA/AM-92/27, August 1992.
- Muir, H; Bottomley, D; Hall, J; *Aircraft Evacuations: Competitive Evacuations in Conditions of Non-Toxic Smoke*, Civil Aviation Authority UK, Paper 92005, March 1992.
- Muir, H; Marrison, C; Evans, A; *Aircraft Evacuations: the Effect of Passenger Motivation and Cabin Configuration Adjacent to the Exit*, Civil Aviation Authority UK, Paper 89019, November 1989.
- Rasmussen, PG; Chittum, CB; *The Influence of Adjacent Seating Configurations on Egress Through a Type III Emergency Exit*, Office of Aviation Medicine Report, DOT/FAA/AM-89/14, December 1989.